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SELECTIVE SEARCH FOR THE TARGET PROPERTIES COLOR AND FORM

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SUMMARY

Three search experiments tested whether the preattentive parallel stage of visual processing can selectively guide the attentive stage to a particular known-to-be-relevant-target feature. Subjects searched multi-element displays for a salient green circle which had a unique form when surrounded by green nontarget squares or had a unique color when surrounded by red nontarget circles. In the distractor conditions, a salient item in the other dimension was present as well. As an extension of earlier findings (Theeuwes, 1991), the results showed that top-down selectivity towards a particular feature was not possible, not even after extended and consistent practice. The results reveal that selectivity depends on the relative discriminability of the form and color dimension. In an additional analysis the effect of the distance between target and distractor is examined.

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Selectief zoeken naar kleur en vorm

J. Theeuwes

SAMENVATTING

In drie visuele zoekexperimenten werd onderzocht of het preattentieve parallelle stadium van informatieverwerking, het attentieve stadium selectief kan sturen naar specifieke taakrelevante target eigenschappen. Proefpersonen zochten in multi-element displays naar een groene cirkel die wanneer geplaatst tussen groene vierkanten, een unieke vorm had, en wanneer geplaatst tussen rode cirkels, een unieke kleur had. In de distractie-condities was een opvallend element aanwezig in de andere dimensie. In lijn met eerder onderzoek (Theeuwes, 1991), laten de huidige resultaten zien dat proefpersonen niet in staat waren om zich selectief te richten naar specifieke target eigenschappen zoals een unieke kleur of een unieke vorm. Zelfs na consistente en langdurige oefening, kon selectiviteit niet worden verkregen. De resultaten laten zien dat selectiviteit afhangt van de relatieve discrimineerbaarheid van de target kleur en target vorm. In een additionele analyse wordt het effect van de afstand tussen target en distractor nader onderzocht.

1 INTRODUCTION

This paper deals with the ability of the preattentive parallel stage of visual processing to *selectively* guide the subsequent serial employment of attention. The present approach is based upon the idea that visual information processing consists of two functionally independent stages: An early, pre-attentive stage that operates without capacity limitations and in parallel across the visual field, followed by the later, attentive limited capacity stage that can deal with only one (or a few) item at a time (e.g., Broadbent, 1958, 1982; Neisser, 1967; Treisman & Gelade, 1980).

Theeuwes (1991) showed that the parallel stage *cannot* selectively guide the attentive stage of processing to the task-relevant stimulus dimension: dependent on the relative discriminability of the stimulus dimensions, the presence of an irrelevant item with a unique color interfered with parallel search for a unique form, and vice versa. It was concluded that during preattentive parallel search, subjects were not capable of selectively attending to just the known-to-be-relevant stimulus dimension. In addition, selectivity depended on the relative discriminability of the stimulus dimensions: when searching for a easy-to-be discriminated color (i.e., search for a red item between green nontarget items) the unique form did not interfere, while the unique form did interfere when the color discrimination was made much harder (i.e., a yellow/red target between yellow/green nontargets).

These findings suggested a model which assumes that the preattentive process computes for each stimulus dimension, differences in features resulting in an activation map representing how different each item is from each of the other items within a particular feature dimension (e.g., color dimension, form dimension). This computation results in a difference signal at each location similar to the bottom-up activation in the parallel stage of the Cave and Wolfe's (1990) guided search model. The parallel stage is then followed by a stage involving focal attention which is assumed to be directed serially and unintentionally to the location having the highest activity, the next highest, etc. Since it is assumed that these two stages operate independent of any strategic control, selectivity completely depends on the bottom-up activations caused by the differences in features within different stimulus dimensions. Similar to Sagi and Julesz (1985) and Ullman (1984) it is assumed that the parallel process can only perform a *local mismatch* detection followed by a serial stage in which the most mismatching areas are selected for further analysis.

Although Theeuwes' (1991) findings did not lead to a definitive theoretical statement, the model above describing selectivity solely in terms of bottom-up processing seemed to account best for his data. Yet, many current theories assume that visual selection *is* affected by knowledge of the target-to-be-found, implying that selection is sensitive to top-down processing. For example, the feature integration theory (FIT, Treisman & Gelade, 1980; Treisman, 1988) assumes at least selectivity between stimulus dimensions: subjects simply check for activity signalling a contrasting item in the relevant *target-defining* module and simply ignore the others. According to the Cave & Wolfe (1990) guided search model, the bottom-up activations caused by the differences in features can be altered by top-down activity which depends on the knowledge of the target to be found, suggesting that the parallel stage selectively can guide focal attention to the likely target locations. Other models such as Duncan and Humphreys (1989) and Bundesen (1990) also assume that preknowledge of the target-to-be-found affects selectivity. Note, however, that all these theories proposed a top-down component in order to account for conflicting data with search for targets defined by *conjunctions* of elementary features. The present framework only regards selectivity between target and distractors when each is defined by a unique elementary feature.

In Theeuwes' (1991) experiments showing the absence of selectivity, subjects viewed multi-element displays (5, 7 or 9 elements) in which one item had a unique color while another item had a unique form. Different groups of subjects either searched for an item with a unique color or an item with a unique form. The results indicated that the item unique in the task-*ir*relevant dimension interfered with search for the item unique in the task-relevant dimension. It is important to realize that subjects only knew which *dimension* was relevant. Thus subjects searching for a unique color, received blocks of trials in which a red item was located between green nontargets, or a green item was located between red nontargets. Subjects searching for a unique form, received blocks of trials in which a square was located between circles or a circle was located between squares. Thus subjects did not exactly know the *feature* properties to attend to, i.e., either to search for a red or a green item or for a square or a circle. The same held for the distractor conditions: subjects knew that an item was present in a irrelevant dimension; yet, they did not know the exact feature properties of the distractor. In addition, because target and nontarget display elements continuously switched roles, an automatic consistently mapped (CM) detection response could not develop.

The question remains, then, whether selectivity can be obtained when not only the stimulus dimension is known, but also the exact feature within that dimension (i.e., search for a green item, search for a circle). Such a hypothesis is viable because in the previous study, uniqueness *within a dimension* was defined by the whole stimulus display; for example, within the color dimension, a red item was the target because the other items were green. In addition, in order to provide the most decisive test for the possibility of selectivity during preattentive parallel search, in the present study, subjects searched always for the same target feature (i.e., a green circle) which was never used as nontarget. In line with Shiffrin and Schneider (1977) analysis, this should lead to an automatic detection response of the target.

2 EXPERIMENT 1

Subjects viewed multi-element displays in which the target line segment that determined the correct response was always located in the green circle. For one group of subjects, this green circle was surrounded by 5, 7, or 9 red circles. For the other group of subjects, the green circle was surrounded by 5, 7, or 9 green squares.

2.1 Method

Subjects

Sixteen right-handed subjects, ranging in age from 18 to 28 years, participated as paid volunteers. Eight subjects were randomly assigned to the form condition, and 8 to the color condition. All had normal or correct-to-normal vision and reported having no color vision defects.

Apparatus

An S-R interface with external clocks (accuracy 1 ms) connected to an IBM AT-3 with video-digitizer (Matrox Inc.) controlled the timing of the events, generated video pictures and recorded reaction times (RTs). The response panel was tilted 45°, and consisted of a left and right response key (1 x 1 cm) which were mounted 5.5 cm apart.

The stimuli appeared on a 35 x 23 cm TV monitor (Conrac model 7250 C19). The fixation point and the line segments were presented in white (17.0 cd/m^2) on a black background of .40 cd/m^2. The surrounds were either red or green (CIE xy-chromaticity coordinates of respectively .622/.357 for red and .282/.596 for green) and were matched for luminance (5.5 cd/m^2).

Subjects were tested in a sound attenuated, dimly-lit 2 x 2 x 2 m cubicle (Amplisilent) with their heads resting on a chin rest adjusted to a comfortable height. The TV monitor was located at eye level, 118 cm from the chinrest. An intercom was used for communication with the subject.

Stimuli

The task was very similar to that in Theeuwes (1991). The stimulus field consisted of 5, 7 or 9 elements, equally spaced around the fixation point on an imaginary circle whose radius was 3.4°. Display elements were outline circles (1.4° of diameter) or squares (1.4° on a side) each containing a line segment (0.5°), which was tilted 22.5° to either side of the horizontal or vertical plane. These orientations were randomly distributed in a display. In each display, there was a single green circle which contained a line segment that was oriented either horizontally or vertically, the latter orientation determining the appropriate response key (left for vertical and right for horizontal). For the group of subjects in the "form" condition, the green circle containing the target line segment had a unique form, because it was surrounded by 5, 7, or 9 green squares. For the group of subjects in the "color" condition, the green circle containing the target line segment had a unique color because it was surrounded by 5, 7 or 9 red circles. Because subjects responded to the orientation of a target line segment located among slightly tilted nontarget line segments, the task required focal attention (Theeuwes, 1991) but not a high spatial acuity.

Procedure

The sequence of events was as follows: initially, a white fixation dot (.3°) was presented at the center of the visual field. Six hundred milliseconds prior to display onset the fixation dot increased in size to 2° in order to warn the subject. The stimulus field remained present for a maximum of 4 s until a response was emitted.

The group of subjects in the "form" condition received two conditions: (1) a neutral condition in which the green circle containing the target line segment was surrounded by 5, 7, or 9 green squares, and (2) a distractor condition in which one of these 5, 7, or 9 squares had a red color. The group of subjects in the "color" condition received two conditions as well: (1) a neutral condition in which the green circle containing the target line segment was surrounded by 5, 7, or 9 red circles, and (2) a distractor condition in which one of these red circles was a square. As will be clear, when searching for a unique form ("form" condition) the distracting element had a unique color, and when searching for a unique for color ("color" condition) the distracting element had a unique form. The position of the green circle containing the target line segment in relation to the distracting display element was randomly determined. Fig. 1 shows the various display configurations.

There were two blocks of 144 trials in the neutral condition and two blocks of 144 trials in the distractor condition, the order of presentation counterbalanced over subjects. Display size was randomized within blocks. Each subject performed a total of 576 trials -- that is, a total of 96 trials in each display-size distractor condition. The practice session consisted of 144 neutral and 144 distractor trials.

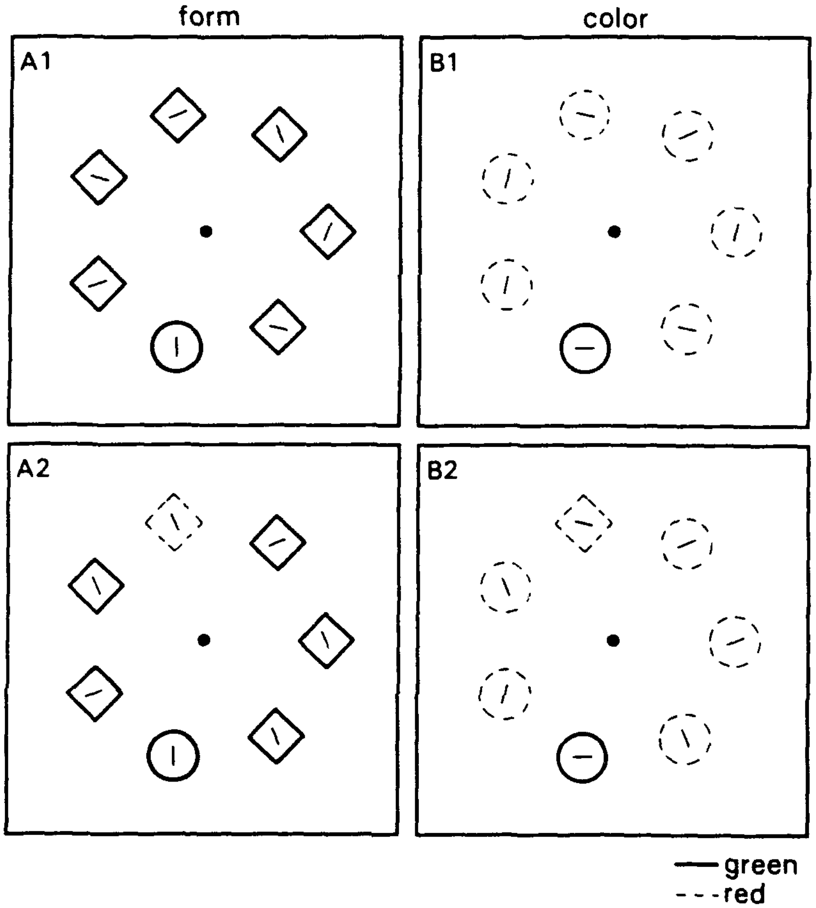

Fig. 1 Examples of Display Size 7. Subjects always search for a green circle surrounded by green squares (left size) or by red circles (right size), either without a distractor (top) or with a distractor item (bottom).

A session consisting of 144 trials lasted approximately 10 minutes, with a 1 minute break after 72 trials. Each block started with 3 dummy trials. Two subjects were run in alternating sessions. Prior to the start of the experiment subjects were instructed to search for the horizontal or vertical target line segment and to press the appropriate response key with one of their thumbs which were resting on the response keys. Subjects were informed about the relation between the location of the target line segment and the unique element. It was emphasized that subjects should fixate the central dot and not move their eyes during the course of any trial. To ensure that subjects followed the instructions, during the practice session eye movements were monitored on-line by means of a infra-red camera. It was stressed that a steady fixation would reduce RT and make the task easier. Both speed and accuracy were emphasized. A warning beep informed the subject that an error had been committed. If no response was made after 4 s, the trial was counted as an error. Before each session, subjects were informed about the upcoming condition.

2.2 Results

Response times longer than 1,000 ms were counted as errors, which led to a loss of well under 1% of the trials. Fig. 2 presents the subjects' mean RT and error percentages in the four conditions. For each of these measures, the form and color conditions were subjected to separate ANOVAs with display size and distractor condition as main factors.

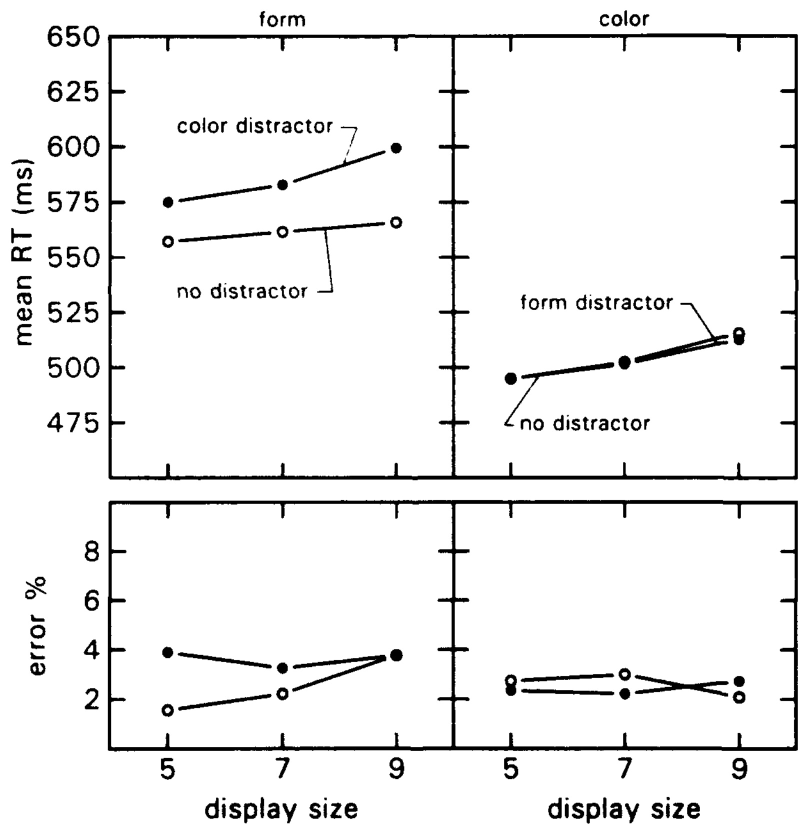

Fig. 2 Experiment 1: Mean reaction time and error percentages for search with or without a distractor for the form (left) and color (right conditions.

In the form condition (Fig. 2A), there was a main effect on RT for display size [$F(2,14) = 8.2$; $p < .01$], and for distractor [$F(1,7) = 13.9$; $p < .01$]. In the color condition (Fig. 2B), there was only an effect on RT for display size [$F(2,14) = 14.3$; $p < .001$]. In order to determine the slopes of the RT functions, the individual mean RTs were submitted to a linear regression analysis. The mean slopes for the form conditions were 2.2 and 6.1 ms for the no-distractor and distractor condition. For the color condition these figures were respectively 5.2 and 4.4 ms. None of these slopes were significantly different from zero (all $t(7) < 1.63$), indicating parallel preattentive search across all items in the display. Inspection of the RT data reveals that search for the green circle when surrounded by green squares is distracted when one of the squares has a unique red color. The reverse does not hold: when searching for a green circle surrounded by red circles, the presence of a unique form does not affect search.

In order to achieve homogeneity of the error rate variance, the mean error rates per cell were transformed by means of an arcsine transformation. For both form and color conditions, none of the error effects were significant, which suggests that the difference in RT are not due to trading speed for accuracy.

2.3 Discussion

The results of this experiment are quite similar to Theeuwes' (1991; exp. 2) earlier findings: when searching for a target item which differs from the other elements in color, the presence of an element with a unique form had essentially no effect. Yet, search for a target item that differs from nontarget elements only in form is slowed down by the presence of a unique color.

The results indicate that knowing the exact target feature (i.e., the target is green and a circle) and knowing the exact distractor feature (i.e., a red square), both consistently mapped throughout the whole experiment, did not result in top-down selectivity: when searching for a green circle surrounded by green squares, the presence of a red square greatly interfered.

The results are in line with the earlier outlined model which assumes that selectivity completely depends on bottom-up processing. According to this model, focal attention is *unselectively* captured by the first feature made available by the preattentive stage. In the present experiment, subjects searched in both "form" and "color" condition for exactly the same stimulus (i.e., a green circle), which was either surrounded by green squares (form condition) or by red circles (color condition). Yet, the "no-distractor" conditions reveal that finding a green circle between red circles is about 60 ms faster than finding the same stimulus surrounded by green squares. This implies that the bottom-up activation of a particular target element depends on the feature properties of the surrounding elements: the green circle between red circles produces a much higher activation than the green circle between green squares. This implies that the difference in color becomes available much earlier than the difference is form, which elegantly accounts for the asymmetric selectivity as presently observed.

3 EXPERIMENT 2

Experiment 2 was designed to test whether differences in bottom-up activations within each dimension can account for the observed asymmetric selectivity. Based on the results of Theeuwes (1991, exp. 3), the color discrimination was made harder than the form discrimination. If attention is switched in the order of the availability of the local feature, it is expected that the asymmetry will switch as well, suggesting that the item with a unique form and not the item with a unique color will interfere.

3.1 Method

Subjects

Sixteen subjects ranging in age between 18 and 24 years participated in the experiment. Eight subjects were randomly assigned to either the form or color condition.

Apparatus

The apparatus was identical to Experiment 1.

Procedure

The task was identical to Experiment 1. Based on Theeuwes (1991, exp. 3) the colors were made so similar that it could be expected that color differences were less salient than form differences. The color CIE xy-chromaticity coordinates were respectively .435/.488 for red and .400/.515 for green and were matched for luminance (6.2 cd/m^2). Design and procedure were identical to Experiment 1.

3.2 Results

Response times longer than 1.000 ms were counted as errors, which led to a loss of about 1.25% of the trials. Mean RT and error percentages are shown in Fig. 3.

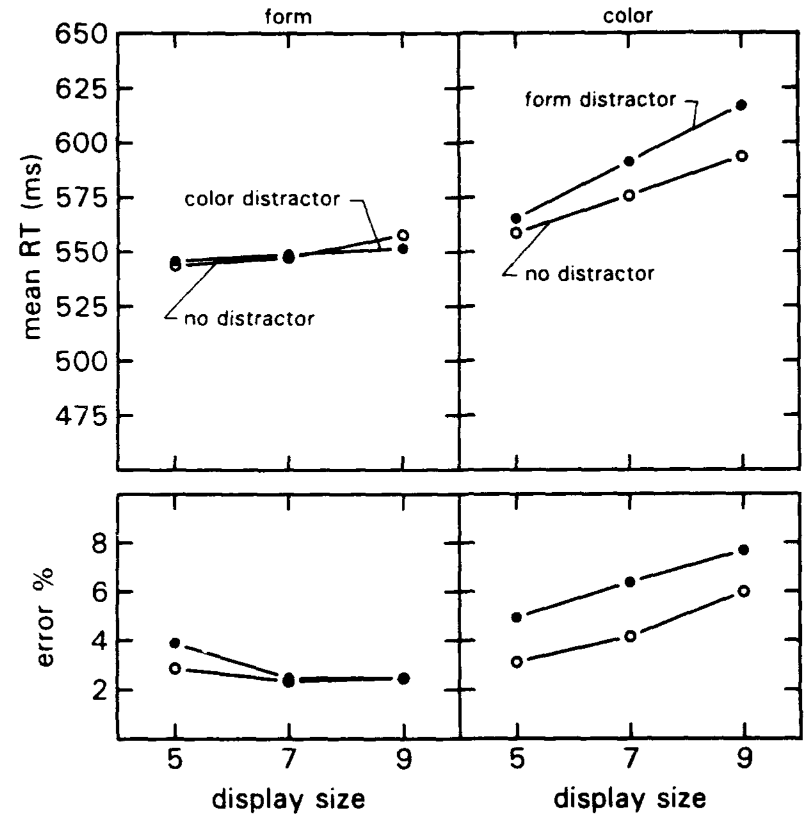

Fig. 3 Experiment 2: Mean reaction time and error percentages for search with or without a distractor for the form (left) and color (right conditions.

In the form condition (Fig. 3A), none of variables showed a significant effect on RT, suggesting that finding a green circle between green squares was not hindered by the presence of a display element with a slightly different color. In the color condition (Fig. 3B), there were main effects on RT for display size [$F(2,14) = 41.1$; $p < .001$] and for distractor [$F(1,7) = 9.1$; $p < .05$], implying that search for a green circle surrounded by circles of a slightly different color is slowed down by the presence of a unique form. The mean slopes for the form conditions were 3.5 and 1.4 ms for the no-distractor and distractor condition. For the color condition, these slopes were 8.7 and 12.9 ms respectively. Only the latter slope differed significantly from zero [$t(7) = 2.0$; $p < .05$], suggesting that in the color condition with a distractor, serial search starts to emerge. The other slopes did not differ for zero (all $t(7) < 1.43$) suggesting parallel search across all items.

The arcsine transformed error data showed that in the form condition none of the effects were significant, whereas in the color condition there was a main effect on RT for display size [$F(2,14) = 10.3$; $p < .01$]. As this analysis indicates that error differences are non-significant or tend to mimic RT, differences in response latencies cannot be attributed to a speed-accuracy trade-off.

3.3 Discussion

The results clearly show that the asymmetric selectivity as observed in Experiment 1 completely depends on the feature properties of the surrounding elements: if form is easier to discriminate than color, than search for form is not hindered by the presence of an element with a unique color, whereas search for color is affected by the unique form. Contrary to earlier findings (Theeuwes, 1991), the present experiment shows a complete reversal of the asymmetric selectivity between form and color. The results provide strong evidence for the earlier outlined model which assumes that selectivity completely depends on the bottom-up activations caused by differences in feature within stimulus dimensions. It assumes that focal attention is attracted to the location in the order of the availability of the difference signal at each location in the display. For example, attention may be attracted to a location of the difference signal as soon as the difference signal exceeds a particular threshold activation. Thus, focal attention is attracted to the location of the feature that "pops-out" first, irrespective of whether that feature is target or a distractor.

4 EXPERIMENT 3

Experiments 1 and 2 showed that selectivity for the green circle completely depends on the bottom-up activation caused by the surrounding elements. Selectivity could not be obtained by top-down processing: knowing the exact feature properties and the consist mapping of targets and nontarget attributes did not result in selectivity. These finding are at odds with many models suggesting that selectivity is affected by top-down processing (i.e., Cave & Wolfe, 1990; Duncan & Humphreys, 1989; Treisman, 1988).

Reasons for not obtaining selectivity might be that 576 experimental and 288 practice trials are not enough to induce top-down selectivity, although usually, in these type of tasks, subjects receive much less trials. Experiment 3 was designed to test this hypothesis. Each subject received in total 288 practice trials followed by 1728 experimental trials.

4.1 Method

Subjects

Eight subjects ranging in age between 19 and 25 years participated in the experiment.

Apparatus

The apparatus was identical to Experiment 1. The display elements were either green or red (same CIE xy-chromaticity as in Experiment 1) and had a luminance of 6.8 cd/m^2.

Procedure

The task was identical to Experiment 1, except that only the "form" condition was employed, that is, subjects searched only for a green circle among green squares. In the neutral condition, all squares were green, whereas in the distractor condition one of the squares was red.

Subjects received 144 neutral and 144 distractor practice trials followed by 6 blocks of 144 trials in the neutral condition and 6 blocks of 144 trials in the distractor condition, the order counterbalanced over subjects.

4.2 Results

Response times longer than 1,000 ms were counted as errors. Mean RT and error percentages divided in three blocks of 576 trials are shown in Fig. 4.

The individual mean RTs were submitted to an ANOVA with practice (section 1, 2, 3), display size (5, 7, 9) and distractor as factors. There was a main effect on RT for both display size and distractor, [$F(2,14) = 18.6$; $p < .001$ for display size; and $F(1,7) = 14.4$; $p < .01$ for distractor]. Note that there was not a main effect on RT for practice, nor did practice interact with any of the other variables, suggesting that consistent practice did not change any of the effects. For the no distractor condition slopes were 3.2, 4.5, 6.0 ms for section one through three. For the distractor condition these measure were 5.9, 5.2, 7.0 ms. Only this latter slope differed significantly from zero [$t(7) = 2.1$; $p < .05$]. The overall analyses suggests, as evident in Fig. 4, that consistent practice does not lead to a overall RT reduction nor to a significant change in the relations between the variables, although it appears that the distractor effect is somewhat reduced in the second section.

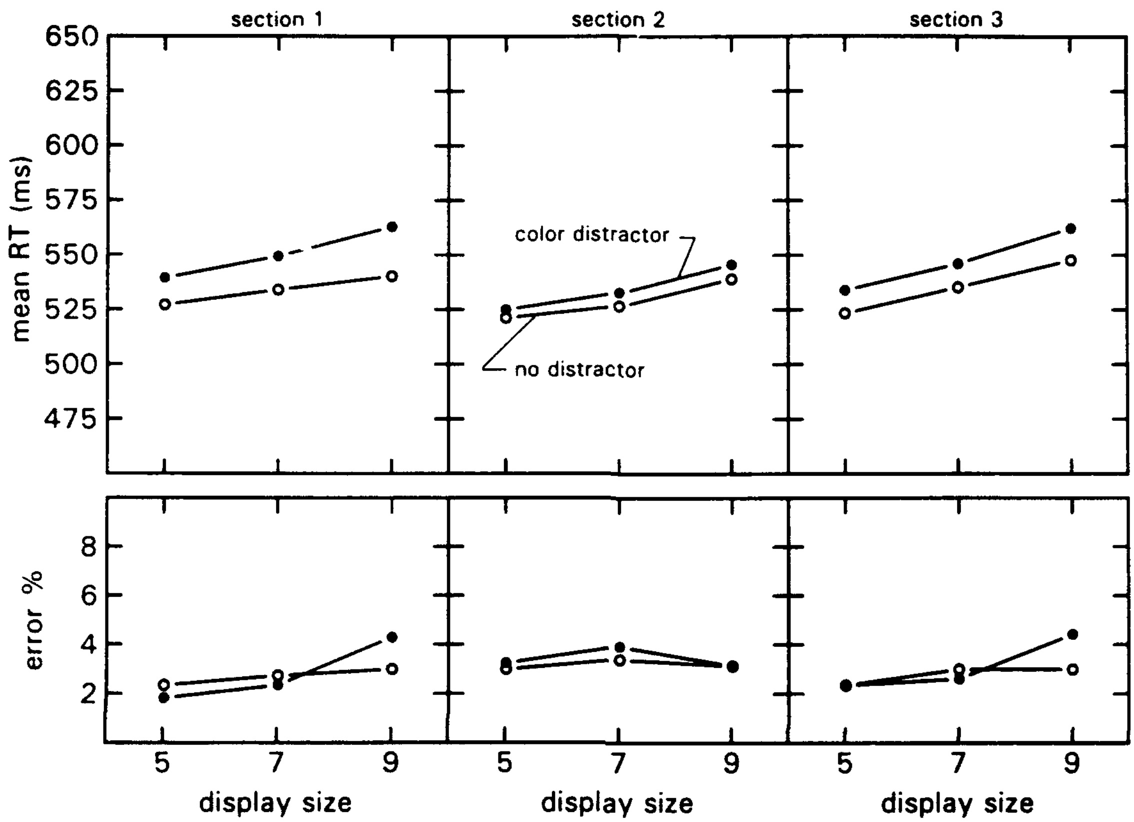

Fig. 4 Experiment 3: Mean reaction time and error percentages for search with or without a distractor separated in three levels of practice.

The arcsine transformed error data showed only a main effect on RT for display size [$F(2,14) = 4.7$; $p < .05$]. Because this analysis indicates that error differences are non-significant or tend to mimic RT, differences in response latencies are not due to a speed-accuracy trade-off.

4.3 Discussion

The results of this experiment are fairly clear, and confirm the conjecture that even after extensive practice complete top-down control is not possible: even after extended practice, subjects lack the ability to simply ignore the known-to-be-irrelevant color. The finding that practice does not alter the overall RT level suggests that the lack of selectivity cannot be attributed to an insufficient practice. Apparently, the task is so simple that the initial 288 practice trials are enough to completely master the search task at a level which does not change with practice.

5 GENERAL DISCUSSION

The present experiments were designed to examine the extent to which the parallel preattentive stage can *selectively* guide the subsequent serial employment of attention. As the previous study (Theeuwes, 1991) already indicated that during preattentive parallel search selectivity towards a particular stimulus *dimension* is not possible, the present study extends these earlier findings and shows that selectivity towards a known-to-be-relevant stimulus *feature* is not possible as well. In addition, selectivity cannot even be obtained after extended and consistent practice.

The present results are in line with the earlier outlined model which assumes that the preattentive process calculates differences in features within dimensions resulting in a pattern of activations at different locations, followed by an automatic shift of focal attention to the location of the feature that "pops-out" first. Such a pop-out occurs irrespective of whether the popping-out feature is a target or a distractor. The operation of the preattentive process is equivalent to the bottom-up component of the Cave & Wolfe (1990) guided search model. For example, the color activation at a particular location is calculated by finding the difference between the color at that location and the color at each of the other locations, and then combining all these differences. Thus, when an item with a unique color and another item with a unique form are present simultaneously, the operation of the preattentive process gives rise to large difference signals at each of the locations of the odd items. Contrary to the claim of Cave & Wolfe (1990), the lack of selectivity as presently found suggests that the parallel stage cannot *identify* anything, and therefore cannot guide elements that are closest to the target value. In fact, the lack of selectivity suggests that the preattentive process has no access to the origins of the difference signals (e.g., whether they are caused by a unique color or a unique form). Therefore, knowing the exact target value (i.e., top-down effect) cannot affect the operations of the preattentive process because at the preattentive level, this information is not yet available. Only after entering the second stage of focal attention (i.e, after being selected), knowledge regarding the target properties may affect processing. Yet, these are top-down effects operating on items which already have been *selected*. Because the preattentive parallel stage is top-down impenetrable, subjects are not capable of activating the green target color or the circular target form (top-down activation of target values as for example suggested by Cave & Wolfe, 1990) nor can they inhibit the squared form distractor or the red color distractor (top-down inhibition of distractor values as for example suggested by Treisman & Sato, 1990). Because the operations of the preattentive process are not under intentional control and not sensitive to perceptual load (i.e., the absence of a display size effect) it can be argued that preattentive processing is strongly automatic because it satisfies both the load insensitivity and the unintentionality criterion of automaticity (see also Theeuwes, 1991).

The observation that the nonrelevant item affects processing of the relevant item is at odds with various theories of visual search that assume top-down effects on the parallel stage of processing (i.e., Cave & Wolfe, 1990; Duncan & Humphreys, 1989; Treisman & Sato, 1990). Yet, there are various reasons why Theeuwes (1991) and the present study, do, unlike others, show interference from the nonrelevant dimension. First, because the interference effects are relatively small (about 15 to 25 ms), the addition of noise to the display will obscure the interference effect, especially because the conclusion that there is no interference is reached by accepting a null effect. For example, noise is introduced when the display elements are not presented in a regular pattern around the point of fixation, but in matrix array which causes an irregular pattern (i.e., clumps of display elements) especially with smaller display sizes. Problems with accepting a zero effect is revealed, for example, by Pashler's texture segregation studies (1988): Experiment 2 suggested that irrelevant color heterogeneity did not interfere with search for a particular form, whereas Experiment 4 (basically a replication) showed highly significant interference effects of the same color variation. Second, it order to disclose interference effects at the preattentive parallel level, it must be ensured that search is performed in parallel. If search is partially serial then the effect of the distractor will obviously be attenuated. Note for example that in texture segregation studies investigating the interference of irrelevant dimensions (e.g., Pashler, 1988; Callaghan, 1989) there is no possibility to check whether segregation is performed in parallel or partially serially. Third, the present study (and Theeuwes, 1991) employed a task in which there is a clear separation between perceptual- and response-selection factors. Because subjects responded to the orientation of the target line segment located in a perceptually discrepant display element, the task is what Duncan (1985) called a "compound" search task in which the stimulus information separating target from nontargets tells nothing about which of the possible responses to choose. In this way it is ensured that the RT data reflect effects operating at the early stage of *perceptual* processing rather than on processing operations occurring after the item has already been selected. For example, knowing the task-relevant stimulus feature might speed up the identification of an item *that has already been selected*, i.e., it is feasible that after entering the second stage of processing less sensory evidence is required to decide whether an item is a target or a distractor (e.g., Broadbent's response set, 1970, 1982). It is very well possible that perception and response selection factors are confounded in various search tasks (for example, in the typical "target present-absent" tasks).

5.1 Target-distractor distance effects in Experiments 1-3

An additional analysis which does not particularly bear on the conclusions reached above was performed on the data. In conditions in which the task irrelevant item interfered with search for the task relevant item, mean RT as a function of the distance between the location of the target item and the location of the distractor item were calculated. Although the present study was not designed to test particular hypotheses regarding distance effects, the results of this analysis may reveal the mechanisms underlying preattentive parallel search.

Mean RT as a function of distance between target and distractor were calculated for each display size separately. Thus for display size 5, target and distractor were separated by either none or 1 nontarget item. For display size 7, there were either none, one or two items in between target and distractor, and for display size 9 there were either none, one, two, or three items between target and distractor. Only for the condition in which there was a distracting effect of the nonrelevant dimension, this computation was performed (i.e., Experiment 1, the "form" condition; Experiment 2, the "color" condition; and for Experiment 3, the "form" condition collapsed over sections). For each experiment, separate ANOVAs with distance as a factor showed in all experiments a clear distance effect on RT only for display size 9 {for Experiment 1 [$F(3,21) = 3.7$; $p < .05$]; for Experiment 2 [$F(3,21) = 4.2$; $p < .05$]; and for Experiment 3 [$F(3,21) = 6.2$; $p < .01$]}. In these conditions there were no effects of distance on transformed error rates. The effect of distance between target and distractor in relation to the RT of display size 9 in the "no distractor" condition are shown in Fig. 5. The visual angle is the separation between target and distractor measured on the imaginary circle on which the elements were presented.

The analysis suggests, as is evident in Fig. 5, that in all experiments the size of the interference effect depends on the distance between the target and distractor: the closer the distractor is to the target, the larger the interference effect.

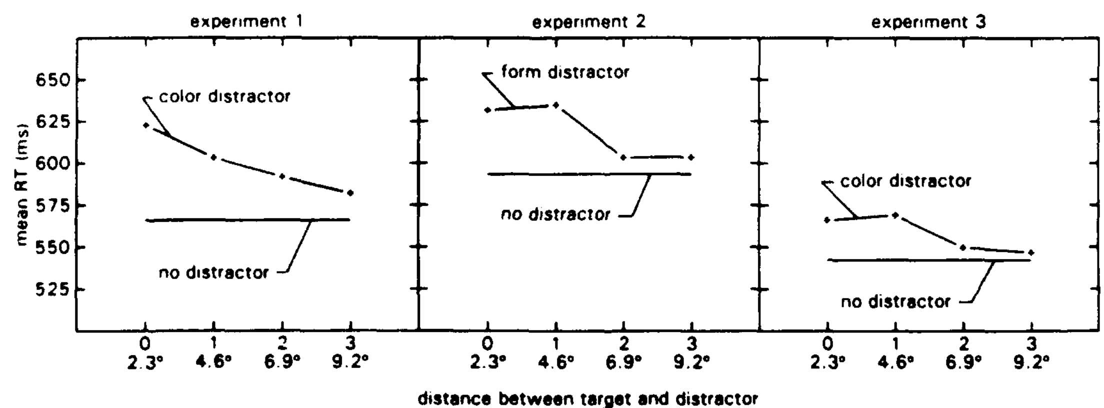

Fig. 5 Mean reaction times as a function of the distance between target and distractor (in items and visual angle) for display size 9 for all experiments.

The results appear to be quite puzzling. If color and form are really separable dimensions and are coded independently and spatially in parallel (e.g., Treisman

& Gelade, 1980) then an explanation for the distance effect should originate at the attentive stage. Yet, given the operation of the attentive stage, there is no reasons why a close distractor would produce more interference than a distant distractor. In fact, one would expect that a more distant distractor would produce *more* interference because erroneous attention attraction by a distant distractor would require more time to re-shift attention to the location of the target item than when attention is attracted by a distractor close to the target. Yet, the data suggest the opposite.

As an alternative explanation, it might be assumed that the interference occurs at the preattentive stage, i.e., when it is assumed that color and form are only to some extent coded independently and spatially in parallel. Consider for example search for a green circle between green squares. If it is assumed that squares close to the target circle will contribute more to the bottom-up activation in the form dimension then squares further away (as hinted by Cave & Wolfe, 1990, p.209), then the disruption caused by the irrelevant color will be larger when breaks the pattern of squares close to the target than when it brakes a pattern of squares further away from the target. Because this disruption causes a slower built-up of activation within the form dimension, it will take longer before attention is shifted to the unique form. In other words, the level of activation depends simply on the signal-to-noise ratio: an item which is surrounded by a homogeneous group of contrasting items will give rise to a large activation within that dimension. An item -- even from another *separable* dimension -- can reduce this activation especially when it disrupts the homogenous pattern close to the target item. This mechanism seems to be similar to the "weight linkage" process of the Duncan & Humphreys (1989) model, which refers to the ease by which similar nontargets can be rejected.

6 CONCLUSIONS

The present study demonstrates that the parallel stage of visual processing cannot selectively guide the attentive stage to just the known-to-be-relevant target feature. These findings are explained by a model which assumes that the preattentive stage calculates automatically differences in features within stimulus dimensions, followed by an attentive stage which automatically shifts to the location of the feature that pops-out first.

Alternatively, the distance effect suggests that the lack of selectivity may not necessarily reside at the attentive stage but might also be caused by interferences at the preattentive stage. Rather than assuming that the lack of selectivity is due to a incorrect shift of focal attention to the location of the distractor, the addition of the irrelevant item -- even an item in another separable dimension --, may simply add noise to the display. The distance effect suggests that this noise progressively affects the operation of the preattentive process when the distractor is closer in space to the target. Because noise reduces the build-up of activation of the target relevant dimension, complete selectivity is not obtained. Note that a combination of explanations is feasible as well: at the attentive stage, attention may be attracted to the location of the distractor; yet, when the distractor is relatively close to the target, there may be a reduced built-up of activation at the preattentive stage.

It should be realized that the present experiments were not designed to explore the distance-interference effects. Therefore the conclusions which were derived from the distance analysis should be considered with great care. Further investigation is required to arrive at a complete characterization of preattentive and attentive processing of primitive features, yet the analysis of distance effects seems to be promising.

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Three search experiments tested whether the preattentive parallel stage of visual processing can selectively guide the attentive stage to a particular known-to-be-relevant-target feature. Subjects searched multi-element displays for a salient green circle which had a unique form when surrounded by green nontarget squares or had a unique color when surrounded by red nontarget circles. In the distractor conditions, a salient item in the other dimension was present as well. As an extension of earlier findings (Theeuwes, 1991), the results showed that top-down selectivity towards a particular feature was not possible, not even after extended and consistent practice. The results reveal that selectivity depends on the relative discriminability of the form and color dimension. In an additional analysis the effect of the distance between target and distractor is examined.

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